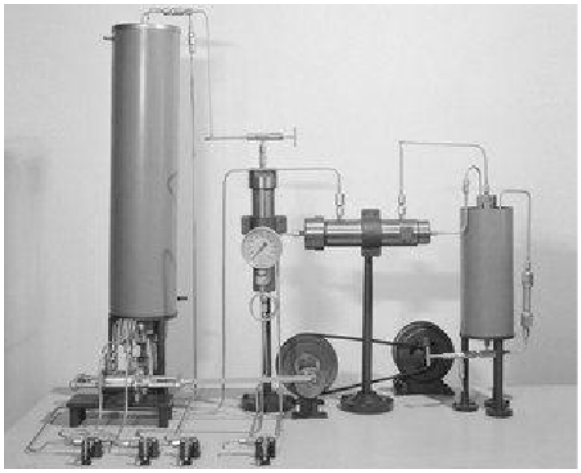
1(a). 100 years ago, Fritz Haber was the first scientist to successfully react nitrogen gas from the air to make a compound.

He used laboratory apparatus similar to this.



Haber reacted small amounts of nitrogen and hydrogen in a closed system to make ammonia.
The reaction is exothermic.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

He investigated how changing the conditions affected the yield.

What effect does increasing the pressure, temperature and using a catalyst have on the yield?

---

[3]

(b). Haber's reaction vessels were too small scale to make large amounts of ammonia.

Karl Bosch scaled up Haber's laboratory reaction to an industrial scale process.

Compare Karl Bosch's industrial scale process with Haber's laboratory reaction.

---

[3]

(c). Ammonia is used to make fertilisers for agriculture.

Ammonia provides nitrogen compounds to make crops grow faster.

Give the names of the **two** other important elements that fertilisers provide.

--- and ---

[2]

2(a). Hydrogen is used on an industrial scale to make fertilisers.

One reaction pathway for making hydrogen is methane gas reacting with steam in a two stage process.

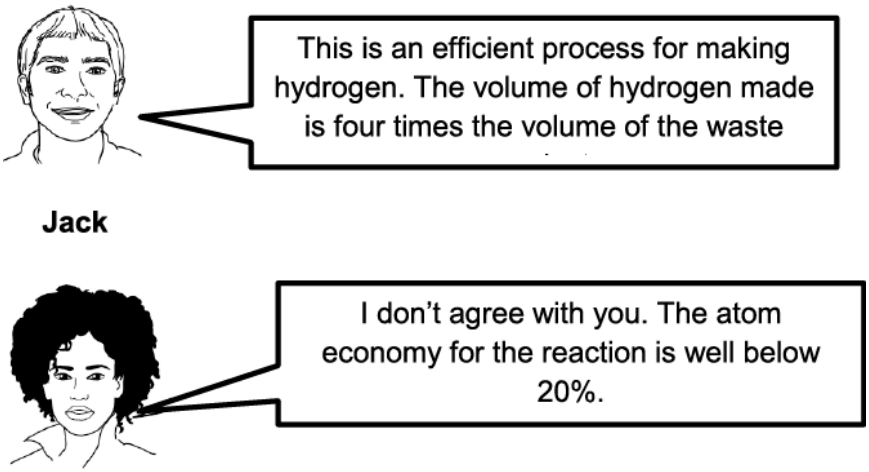
Stage 1: $CH_4 + H_2O \rightleftharpoons CO + 3H_2$

Stage 2: $CO + H_2O \rightleftharpoons CO_2 + H_2$

The overall equation for the reaction is ….

$$CH_4 + 2H_2O \rightleftharpoons 4H_2 + CO_2$$

Jack and Liz discuss the process.



(i) What is the waste product of this process?

---

[1]

(ii) Use a calculation to show that the volume of hydrogen made is four times the volume of the waste product.

(One mole of gas has a volume of 24 dm^3 at room temperature and pressure).

[2]

(iii) Use the overall equation for the reaction to calculate the atom economy.

atom economy _____ [3]

(iv) Explain why the atom economy for the process is low even though the volume of hydrogen made is high.

---

[2]

(b). Liz also says that she thinks that this method of making hydrogen is not sustainable in the long term.

Explain why Liz may think this.

---

[4]

3(a). Ammonia for making fertilisers is made in this reaction.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

In a closed container, this reaction does not give 100% yield, even if the reaction is left to run for a very long time.

Explain why.

[2]

(b). On an industrial scale, conditions for the reaction between hydrogen and nitrogen can be chosen to increase the rate of reaction and the yield.

Which conditions increase only the rate, which increase only the yield and which increase both?

Put a tick (?) in one box in each row.

Condition	Increases rate only	Increases yield only	Increases both rate and yield
High temperature			
High pressure			
Use of a catalyst			
Recycling unreacted hydrogen and nitrogen			

[3]

4(a). A company makes chemical compounds and uses them to make products such as fertilisers and drugs.

The table gives information about these products.

Type of product	Type of manufacture	Use	Other notes
fertilisers	bulk	spread on soil to help crops grow	Company makes ammonium nitrate for fertilisers. Millions of tonnes of fertiliser compounds are needed in the UK every year.
drugs	fine	used as medicines by people and animals	Company makes a range of different compounds for use to make drugs. Purity of compounds very important.

Use the information in the table to explain why fertilisers and drugs need to be manufactured differently.

---

[2]

(b). Millions of tonnes of hydrogen are made every year. In industry, most hydrogen is made by a reaction between methane gas and steam.

methane	+	steam	→	hydrogen	+	carbon dioxide
CH_4	+	$2H_2O$	→	$4H_2$	+	CO_2

The table shows some information about the process.

Feedstocks	methane (natural gas) and water
Number of stages in process	2
Temperature needed	700–1100 °C
Energy source	burning some of the methane gas
By-products	none
Waste product	carbon dioxide gas
Atom economy	15%

Use the information to help you to explain why this process is **not** sustainable.

The quality of written communication will be assessed in your answer.

[6]

(c). Scientists are working on a new process to produce hydrogen.

The new process uses a reaction that runs at a lower temperature than the reaction between methane and steam.

(i) Which two statements explain why some reactions work at a lower temperature than others?

Put ticks (?) in the boxes next to the **two** correct answers.

The rate of reaction is lower. ☐

The reaction has a lower activation energy. ☐

More gases are made in the reaction. ☐

The reaction uses a catalyst. ☐

Steam is less reactive than hydrogen. ☐

(ii) The new process splits water into hydrogen.

$$2H_2O \rightarrow 2H_2 + O_2$$

The atom economy of the reaction can be calculated using this formula.

$$\text{atom economy} = \frac{\text{total mass of atoms of hydrogen in products}}{\text{total mass of all atoms in reactants}} \times 100\%$$

Use the formula to calculate the atom economy for the reaction.

_____ % **[2]**

(iii) The oxygen made in the new process is considered to be a by-product rather than a waste product.

Explain the difference between a by-product and a waste product.

_____

_____

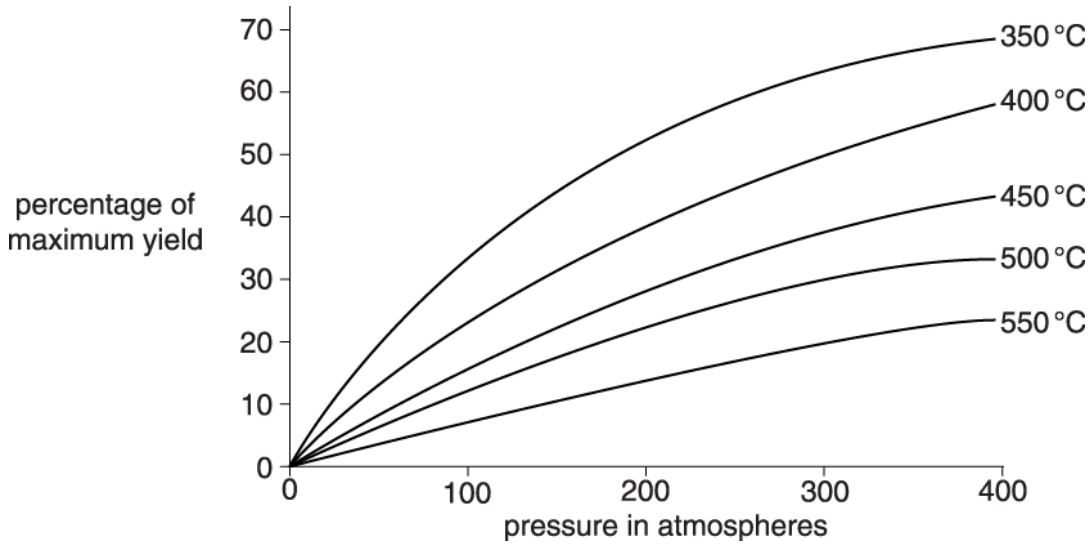
_____

_____ **[2]**

5(a). Ammonia, NH_3, is made from nitrogen and hydrogen by the Haber process.

$$\underset{\text{nitrogen}}{N_2} + \underset{\text{hydrogen}}{3H_2} \rightleftharpoons \underset{\text{ammonia}}{2NH_3}$$

The graph shows how the yield of ammonia is related to both the temperature and the pressure used.



(i) The Haber process uses:

- a catalyst
- a temperature of 450 °C
- 250 atmospheres pressure.

These conditions do not give the highest percentage yield of ammonia.

Explain why these conditions are a compromise to make the process economically viable.

The quality of written communication will be assessed in your answer.

---

[6]

(ii) The reaction between nitrogen and hydrogen to form ammonia is reversible.

The reaction mixture can reach a dynamic equilibrium.

Which of these statements describes what is happening at equilibrium?

Put ticks(✓) in the boxes next to the **two** correct statements.

The reaction between nitrogen and hydrogen has stopped. ☐

The forward and reverse reactions happen at the same rate. ☐

All of the nitrogen and hydrogen react to make ammonia. ☐

The concentration of ammonia is increasing. ☐

The concentrations of nitrogen, hydrogen and ammonia are constant. ☐

[2]

(b).

(i) Work out the relative formula mass (RFM) of ammonia, NH_3.

RFM of ammonia = _____ **[1]**

(ii) What is the mass of ammonia that would be made if 1.0 tonne of nitrogen reacted completely with hydrogen?

Show your working.

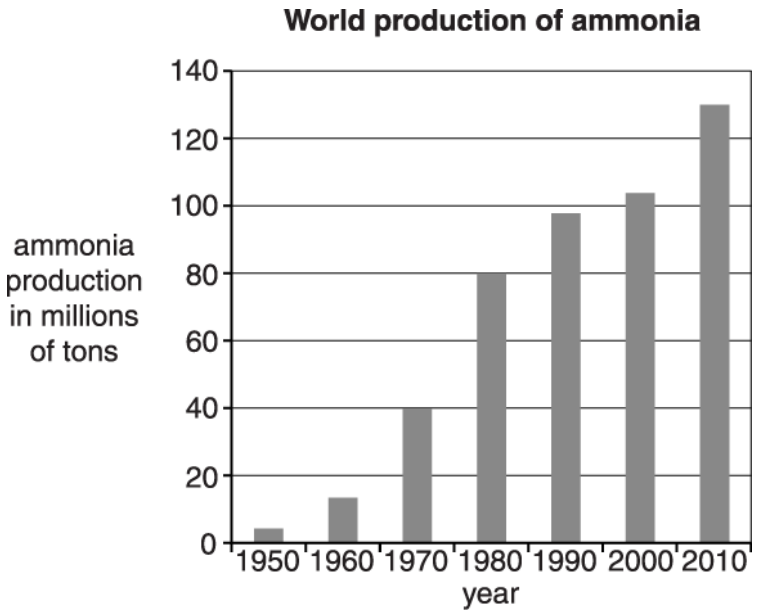
mass of ammonia = _____ tonne **[2]**

(iii) A factory converts 95 % of the nitrogen into ammonia.

What mass of ammonia does this factory make from each tonne of nitrogen?

mass of ammonia = _____ tonne **[1]**

(c). Look at the bar chart.



The main use of ammonia is to make fertilisers.

Large scale use of fertilisers made from ammonia causes environmental problems.

Write about these problems, and explain why they have got worse over the last 60 years.

[3]

6. The energy changes for reactions in industry are carefully controlled.
Why is this important?

Put ticks (✗) in the boxes next to the **two** best answers.

Energy given out by reactions can be used to heat buildings.	☐
Reactions that give out energy use too much fuel to keep them hot.	☐
Energy changes in reactions affect the rate.	☐
Containers for reactions may be damaged by extreme temperatures.	☐
Reactions that take in energy need to be continuously cooled.	☐

[2]

7. When chemical engineers design an industrial process, they make it as sustainable as possible.

To make a process more sustainable, chemical engineers use:

- **renewable** feedstock
- reactions with high **atom economy**.

Explain what the terms **renewable** and **atom economy** mean, and how each can make a process more sustainable.

The quality of written communication will be assessed in your answer.

[6]

8(a). In the Haber Process, nitrogen and hydrogen react to make ammonia, NH_3.

Write a balanced symbol equation for this reaction.

---

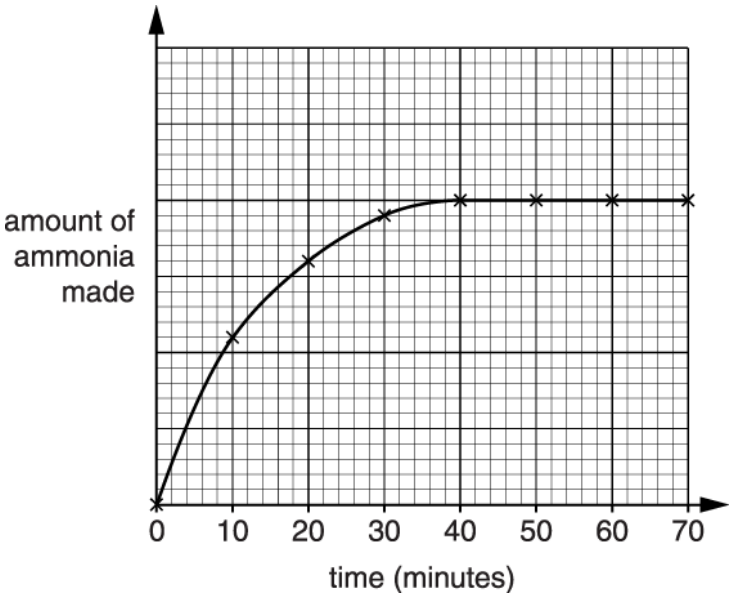
[2]

(b). State and explain the main use of ammonia.

---

[2]

(c). The reaction between nitrogen and hydrogen is reversible and can reach an equilibrium.
Ann heats some nitrogen and hydrogen with a catalyst in a closed container.
She plots a graph to show how the amount of ammonia made changes with time.



(i) At what time does the amount made stop increasing?

---

[1]

(ii) The amount made stops increasing when the reaction reaches equilibrium.
At this time the reaction to make ammonia is still taking place.

Explain why the reaction to make ammonia is still taking place but the amount made is not increasing.

---

[3]

(iii) Put a tick (✓) in the box next to the name of this type of equilibrium.

active equilibrium ☐

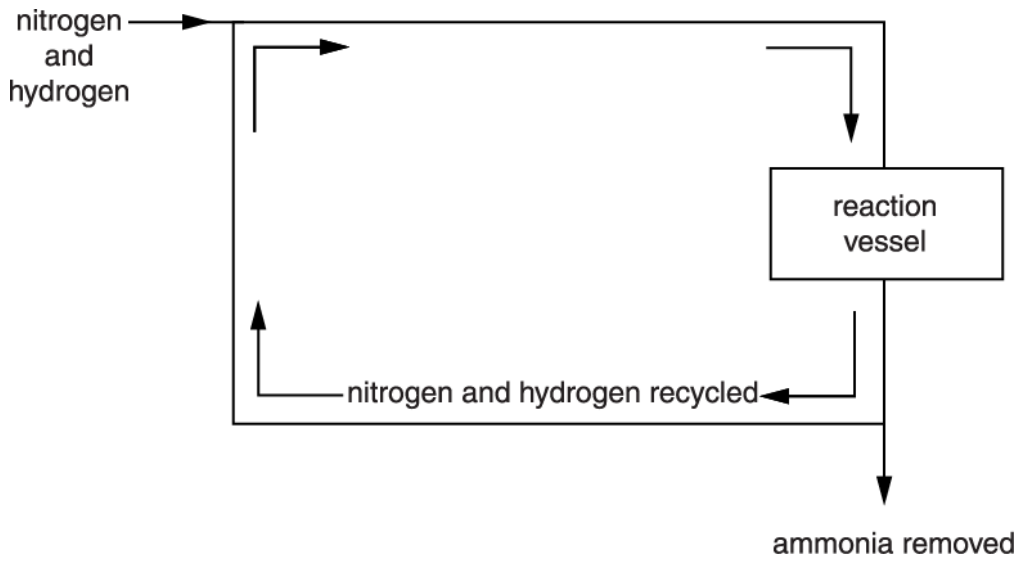
dynamic equilibrium ☐

fixed equilibrium ☐

static equilibrium ☐

[1]

(d). In the Haber Process, most of the nitrogen and hydrogen has to be recycled to make the process run efficiently.



Explain how and why this recycling affects the total yield of the reaction, and why so much has to be recycled.

---

[3]

9(a). Millions of tonnes of ammonia are made every year.

Ammonia is made by reacting nitrogen and hydrogen.
The only product for this reaction is ammonia.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

If nitrogen and hydrogen are heated together in a flask, the reaction is slow and only a low percentage of the reactants are converted.

Suggest why so little is actually produced and how the Haber process overcomes this problem.

The quality of written communication will be assessed in your answer.

[6]

(b). Ammonia can be used to make many different products.

One product is explosives that can be used to make weapons.

Dave says that we should not make ammonia because it is used to harm people.

Eve does not agree.

Give some arguments Eve could use to support her view.

--- [3]

10. Millions of tonnes of hydrogen are made every year.

The hydrogen is usually made from methane.

The process starts with methane and steam, and makes hydrogen and carbon dioxide.

Scientists calculate the atom economy to help decide how green the process is.

$$CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$$

Formula	Relative formula mass (RFM)
CH_4	16
H_2O	18
H_2	2
CO_2	44

(i) Use the following formula to calculate the atom economy for the production of hydrogen in this process.

$$\text{atom economy} = \frac{\text{mass of atoms of hydrogen}}{\text{mass of atoms of all reactants}} \times 100\%$$

answer = _____ % **[2]**

(ii) Why does this suggest that the process is not very green?

_____

_____

_____ **[2]**

11.

Fizzy water can be found naturally.

The water is fizzy because it contains dissolved carbon dioxide gas. The carbon dioxide comes from the decomposition of rocks that contain carbonate compounds.

One compound found in rocks is magnesium carbonate.

Ali investigates the decomposition of magnesium carbonate by heating a small amount in a test tube. This is the equation for the reaction.

$MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$

Calculate the atom economy for the production of carbon dioxide in this reaction.

Use the formula: $\text{atom economy} = \frac{\text{mass of atoms in desired product}}{\text{total mass of atoms in reactants}} \times 100\%$

Give your answer to **1** decimal place.

Atom economy = ---------- % **[4]**

12(a) This is an equation for a reaction that occurs in a lightning flash.

.

$N_2 + O_2 \rightleftharpoons 2NO$

Very high temperatures are needed.

Scientists can use this reaction to make nitrogen compounds from gases in the air.

(i) Suggest a use for these compounds.

---

[1]

(ii) The scientists discuss increasing the pressure on the reaction.

Describe and explain the effect on the equilibrium position.

---

[2]

(b). There are several ways of making nitrogen compounds from nitrogen gas in industry.

Give **two** reasons why scientists may choose this reaction and **one** against.

Reason for ---

Reason for ---

Reason against ---

---

[3]

13. Nitrogen oxides are pollutant gases that are produced when coal is burned in a power station.

Which statements about nitrogen oxides are **true** and which are **false**?

Put a tick (✓) in one box in each row.

	True	False
Nitrogen oxides form in an oxidation reaction.		
Nitrogen oxides come from impurities in the coal.		
Nitrogen oxides are acidic oxides.		
Ammonia is an example of a nitrogen oxide.		

[2]

END OF QUESTION PAPER

Question			Answer/Indicative content	Marks	Guidance
1	a		increasing the pressure increases the yield ✓ increasing the temperature decreases the yield ✓ using a catalyst has no effect on yield ✓	3	
	b		larger scale / larger vessels ✓ reactant / products continuously added / removed / continuous process ✓ conditions used to compromise between rate and yield / high temperature to increase rate but reduces yield ✓	3	
	c		phosphorous ✓ potassium ✓	2	
			Total	8	
2	a	i	carbon dioxide ✓	1	
		ii	H_2: 4 × 24 = 96 dm^3 ✓ CO_2: 1 × 24 = 24 dm^3 ✓	2	ALLOW clear indication of 4 moles:1 mole ratio in calculation for (1) mark
		iii	FIRST CHECK THE ANSWER ON THE ANSWER LINE If answer = 15.38 award 3 marks 8 / 52 × 100 = 15.4 / 15.38 % uses 8 in calculation ✓ uses 52 in calculation ✓ substitutes and computes correctly ✓	3	ALLOW any number of (correct) sig figs correct answer scores (3)
		iv	hydrogen has a low (relative atomic)mass ✓ all gases have the same (molar) volume / mass of carbon dioxide is much greater than hydrogen ✓	2	

Question			Answer/Indicative content	Marks	Guidance
	b		methane is a fossil fuel / in finite supply ✓ waste product is carbon dioxide ✓ carbon dioxide causes climate change ✓ idea that process cannot continue without causing harm to the environment / cannot continue because raw materials will not be available ✓	4	
			Total	12	

Question			Answer/Indicative content	Marks	Guidance
3	a		reaction is reversible / explains reversible idea / ammonia breaks down again into nitrogen and hydrogen; (1) [reaches] equilibrium (1)	2	Examiner's Comments Able candidates appreciated that an equilibrium would be reached when nitrogen and hydrogen are heated together in a closed container, and went on to give some explanation. Others suggested that the conditions must have reduced the yield, that the reaction produces waste products, and that the reaction does NOT reach equilibrium.
	b		<table><tr><th>Condition</th><th>Increases rate only</th><th>Increases yield only</th><th>Increases both rate and yield</th></tr><tr><td>High temperature</td><td>✓</td><td></td><td></td></tr><tr><td>High pressure</td><td></td><td></td><td>✓</td></tr><tr><td>Use of a catalyst</td><td>✓</td><td></td><td></td></tr><tr><td>Recycling unreacted hydrogen and nitrogen</td><td></td><td>✓</td><td></td></tr></table>	3	All 4 rows correct (3) 3 or 2 rows correct (2) 1 row correct (1) Examiner's Comments Almost all candidates understood that recycling unreacted hydrogen and nitrogen would affect the yield and not the rate of the reaction. They had only a partial understanding of the links between yield and rate with temperature, pressure and catalyst, but the misunderstandings were spread across all the possibilities without any clear threads.
			Total	5	

Question			Answer/Indicative content	Marks	Guidance
4	a		idea that fertiliser/bulk chemicals are in demand/ needed/made/used on a large scale / made continuously OR drugs/fine on a small scale / batch process; (1) monitoring of purity is easier for fine processes; (1) links fertiliser/bulk chemicals to idea of one product **OR** drugs/fine chemicals to the need to change products; (1)	any 2	**BOD** drugs need to be pure **Ignore** 'consumed by humans' without further explanation **Examiner's Comments** As this was the first question on the paper examiners gave credit for the identification of relevant statements from the table, without demanding that candidates take their answers any further than that. Most candidates were able to link bulk manufacture to the need to produce millions of tonnes a year. Interestingly, many candidates then suggested that drugs are examples of the fine chemical industry because they are needed in small quantities. As this is merely the reverse argument to the previous point it was not enough to gain the second mark. A few candidates realised that fine manufacture was usually associated with the need to carry out small production runs of different substances. Credit was also given to those candidates who suggested the need to control purity as the reason for fine manufacture.
	b		**[Level 3]** Discusses the use of methane, energy and the reaction linked to sustainability. Quality of written communication does not impede communication of the science at this level. (5 – 6 marks) **[Level 2]** Identifies aspects of the process that affect sustainability with clear links. Quality of written communication partly impedes communication of the science at this level.	6	**This question is targeted at grades up to C** **Indicative scientific points may include:** **Sustainability links about using methane** • methane comes from a fossil fuel • methane is in finite supply/will run out / is non-renewable **Sustainability links about energy** • multi-stage processes use more energy • high temperature uses energy • high temperature uses fuel/methane

Question			Answer/Indicative content	Marks	Guidance
			(3 – 4 marks) [Level 1] Makes a statement to link one aspect of the process to sustainability. Quality of written communication impedes communication of the science at this level. (1 – 2 marks) [Level 0] Insufficient or irrelevant science. Answer not worthy of credit. (0 marks)		• methane/fossil fuel is burned to heat process / provide energy Sustainability links about the reaction • waste product/CO_2 [accept CO_2 from burning methane/] causes climate change (**Ignore** pollutant/harms the environment) • atom economy low/ 'only' 15% **BOD** references to 'atom efficiency' but ignore 'efficiency' alone Use the L1, L2, L3 annotations in RM Assessor; do not use ticks. Examiner's Comments There were many excellent explanations for the unsustainable nature of hydrogen production from methane. Both atom economy and global warming were usually well discussed. Examiners were pleased to see how many of even the weaker candidates realised that vague references to 'pollution' and it being 'harmful' would be inadequate, and so made specific mention of global warming. The problem of high temperatures was also well discussed, with only the weakest of candidates suggesting 'cost' or 'the safety of the workers' as a reason for this unsustainability. The factor which was least well covered was the non-renewability when using fossil fuel as feedstock. Many candidates were familiar with the idea that resources might run out, but could not take this idea past the abstract words in order to fit the concept into a cogent framework. Responses such as "it is unsustainable because the water will run out if we use it too much" were not uncommon.

Question			Answer/Indicative content	Marks	Guidance
	c	i	box 2; (1) box 4; (1)	2	**Examiner's Comments** This question tended to be well answered, though Q1ci showed that candidates still do not always read the question carefully enough. A significant number ticked the box for 'the rate of reaction is lower', presumably thinking that they had been asked to *describe* the effect of lower temperature on rate rather than *explain why* some reactions might work at a lower temperature.
		ii	correct answer : 11% (2) Uses 4 OR 36; (1)	2	Accept any number of decimal places 11.111111r **Examiner's Comments** The calculation of atom economy proved to be more stretching at all levels of ability, though examiners were pleased that the vast majority of candidates had shown some suitable working. Consequently a large number gained one mark even though their final answer was incorrect. A very common mistake was to add the mass of the hydrogen to the mass of only one oxygen instead of two.
		iii	by-product/oxygen has another use; ORA(1) waste product is thrown away / must be disposed of; (1)	2	**BOD** 'By-product can be re-used' Waste product mark is for an active event 'thrown away' not a passive 'not needed/ not used' **Examiner's Comments** Many candidates used the same argument both ways round by saying that by-products could be used for other purposes, waste products could not. As in Q1a, these candidates were only able to gain one of the marks.
			Total	**14**	

Question			Answer/Indicative content	Marks	Guidance
5	a	i	**Level 3 (5–6 marks)** Answer uses ideas of equilibrium and rate to explain the compromise choices of both temperature and pressure and why a catalyst is used. Quality of written communication does not impede communication of the science at this level. **Level 2 (3–4 marks)** Answer gives a good explanation for either temperature or pressure or a partial explanation of both. May write about yield rather than equilibrium. Quality of written communication partly impedes communication of the science at this level. **Level 1 (1–2 marks)** Answer discusses the data but gives little or no explanation of the compromise conditions. Quality of written communication impedes communication of the science at this level. **Level 0 (0 marks)** Insufficient or irrelevant science. Answer not worthy of credit.	6	**This question is targeted at grades up to A** **Indicative scientific points may include:** • to be economically viable need to make as much ammonia as possible as quickly as possible temperature ideas • higher temperature shifts equilibrium to left • the higher the temperature the lower the yield • high temperature costs more to maintain • because forward reaction is exothermic / releases heat energy • at low temperature rate is too slow • compromise medium temperature eg about 450°C pressure ideas • higher pressure shifts equilibrium to right • the higher the pressure the higher the yield • because forward reaction decreases pressure / decreases number of molecules • higher the pressure the tougher the reaction vessel has to be so that it does not burst • higher pressure increases cost / risk of process • compromise medium pressure of 250 atmospheres. catalyst ideas • catalyst gives more product in same time • catalyst allows use of lower temperature for same rate • catalyst does not change yield / equilibrium position **Use the L1, L2, L3 annotations in Scoris;**

Question			Answer/Indicative content	Marks	Guidance
					do not use ticks. Examiner's Comments In (i) a six–mark extended–writing question, most candidates made some reference to the compromise for temperature and pressure. The stronger candidates gave explanations for the effect of these parameters on yield. Only the strongest candidates used ideas about dynamic equilibrium in their explanations. Many candidates mentioned use of a catalyst but few realised that this did not affect the yield.
		ii	tick in box 2 (1) tick in box 5 (1)	2	Examiner's Comments In (ii) most candidates chose the correct statements to gain both marks.
	b	i	17	1	Examiner's Comments All but the weakest candidates could correctly calculate the relative formula mass of ammonia to gain the mark in (i). (1 x 14) + (3 x 1) = 17 Some weaker candidate multiplied atomic masses rather than adding them.
		ii	1.0 x (2x17)/28 (1) = 1.2 (1)	2	**allow** 1.21 **ignore** additional figures beyond 3 sig fig if they would round down to 1.21 **allow** ecf from **(i)** **allow** both marks for correct answer without working Examiner's Comments In (ii) only the strongest candidates could complete the calculation correctly. 1.0 x (2x17)/28 = 1.2 tonne Many candidates with incorrect answers included working with a jumble of figures that contained little or no logic.

Question			Answer/Indicative content	Marks	Guidance
		iii	(1.2 × 95/100 =) 1.14	1	**allow** 1.1 **allow** ecf from **(ii)** (ie candidate's answer in **(ii)** x 0.95) **Examiner's Comments** Stronger candidates gained the mark in (iii) even if they did not have the correct answer for (ii), since they correctly calculated 95% of the answer that they gave in (ii). Most candidates could not successfully calculate 95% of their answer in (ii).
	c		fertiliser is washed into rivers causing pollution / eutrophication (1) production of ammonia has increased / use of fertilisers has increased (1) **plus** a link from more ammonia / fertilisers to more pollution (1)	3	**allow** description of eutrophication **Examiner's Comments** Most candidates could describe the polluting effect of fertilisers washed into rivers. Many did this at great length, but only one mark was available for this part of the answer. Fewer stated that the production of ammonia or the use of fertilisers had increased, and only the strongest candidates linked these two ideas to explain why the pollution had increased. A number of candidates incorrectly thought that the pollution was caused by release of ammonia into the environment, or to gases released during the production of ammonia.
			Total	**15**	
6			energy changes in reactions affect the rate (1) containers for reactions may be damaged by extreme temperatures (1)	2	**Examiner's Comments** Most candidates gained at least one mark, usually for identifying that energy changes affect the rate. Fewer knew that containers need to be cooled. Common incorrect choices included thinking that reactions that give out energy use fuel or that reactions that take in energy must be cooled.
			Total	**2**	

Question			Answer/Indicative content	Marks	Guidance
7			Level 3 Explains each term and links at least one to sustainability *Quality of written communication does not impede communication of the science at this level.* (5 – 6 marks) Level 2 Explains each term without reference to sustainability, or explains one term and links it to sustainability *Quality of written communication partly impedes communication of the science at this level.* (3 – 4 marks) Level 1 Explains either 'renewable' or 'atom economy' or 'sustainability'. *Quality of written communication impedes communication of the science at this level.* (1 – 2 marks) Level 0 *Insufficient or irrelevant science. Answer not worthy of credit.* (0 marks)	6	**This question is targeted at grades up to A** **Indicative scientific points may include:** **renewable** • replaces itself • detail ? eg plants regrow • so does not run out / infinite **Ignore** can be renewed / used again **Sustainability links for renewable** • idea of long term use of process • doesn't use up finite resources • available for future generations **atom economy** • measure of the amount of **useful** product 'Helpful' = QWC impeded • high atom economy means little by-product NOT 'waste' • mass [desired] product divided by mass reactants Don't confuse with % yield **sustainability links for atom economy** • desire to limit waste • reduce damage to environment **Use the L1, L2, L3 annotations in Scoris; do not use ticks.** **Examiner's Comments** Candidates tackled this question on sustainability with enthusiasm, though answers were often a little unfocussed. Explanations of renewability often mentioned 'protecting the environment' and 'less pollution', but did not explain what the term 'renewable' actually meant. A minority of candidates did not appear to recognise the term 'atom economy'.
			Total	**6**	

Question			Answer/Indicative content	Marks	Guidance
8	a		$N_2 + 3H_2$? $2NH_3$ Formulae correct = 1 [Correct formulae] balanced = 1	2	equilibrium sign optional, accept ' = ' as alternative to ? accept multiples **Examiner's Comments** Almost all candidates copied out the formula of ammonia correctly, but often struggled with the formulae of nitrogen and hydrogen molecules. A very common answer was $N+H^3$? NH^3 Those who got the formulae correct were almost always able to balance the equation. The equilibrium sign was used in most cases.
	b		fertiliser detail ? for plants / crops / food supply	2	'to help growth and kill pests' CON for 2nd mark **Ignore** as a source of nitrates **Ignore** other uses **Examiner's Comments** The vast majority of candidates knew that the main use of ammonia is in the manufacture of fertilisers. The most common incorrect suggestions were 'hair dyes', 'cleaning products' and 'explosives'.
	c	i	38–40 [minutes]	1	**Examiner's Comments** The graph was interpreted correctly by almost all candidates.

Question			Answer/Indicative content	Marks	Guidance
		ii	Discusses reverse reaction [1] Understands that both reactions happen at the same time [1] at same rate / speed = 1	3	the reaction is reversible / ammonia is broken down = 1 The “same time” point may be by implication Forward and backward reaction occur = 2 ammonia is made and broken down = 2 both reactants and products are reacting = 2 Forward and backward reactions cancel out = first 2 marking points only **Ignore** ‘dynamic equilibrium’ **Examiner's Comments** In explaining why the amounts do not increase when equilibrium has been reached, many candidates were able to talk about the reverse reaction. The most able candidates took this further and stated that the two reactions had the same rate.
		iii	active equilibrium ☐ dynamic equilibrium ☐ fixed equilibrium ☐ static equilibrium ☐	1	**Examiner's Comments** That this type of equilibrium is called “dynamic” discriminated well at the lower end of the range.
	d		not all nitrogen and hydrogen react / so more can react; comment on how little reacts / low efficiency / initial yield low; increase [yield] / more ammonia	3	ignore ‘recycled’ [stem] ‘only a small amount reacts’ = 2 If % yield quoted, accept anything below 50% **Examiner's Comments** The question asked candidates to explain how and why recycling the reagents affected the yield. Whilst most candidates addressed the ‘why’, a significant number did not address the ‘how’ and made general statements such as ‘the yield would be affected’ without suggesting what the change would be.

Question			Answer/Indicative content	Marks	Guidance
			Total	12	

Question			Answer/Indicative content	Marks	Guidance
9	a		[Level 3] Recognises that there is an equilibrium and identifies some conditions and includes a level 3 link. Quality of written communication does not impede communication of the science at this level. (5 – 6 marks) [Level 2] Recognises that there is an equilibrium and identifies some conditions OR Recognises that there is an equilibrium and gives a level 3 link. Quality of written communication partly impedes communication of the science at this level. (3 – 4 marks) [Level 1] Recognises that there is an equilibrium or identifies some conditionsg Quality of written communication impedes communication of the science at this level. (1 – 2 marks) [Level 0] Insufficient or irrelevant science. Answer not worthy of credit. (0 marks)	6	This question is targeted at grades up to A* Level 3 links • recycling [of unreacted material] • high pressure favours forward reaction / increases yield / fewer molecules on RHS • low temperature favours forward reaction / increases yield / exothermic Conditions: • compromise temperature / quotes a suitable value 300?600°C • high[er] temp increases rate • high pressure / quotes a suitable value [25–200atm] • catalyst [iron] • removal of ammonia Equilibrium statements • reaction reversible • there is a backward reaction • involves equilibrium If answer includes incorrect points (e.g. high temperature) then consider quality of communication to be impeded at levels 2 and 3 only. Do not penalise candidates who think that the Haber Process reaches equilibrium. Use the L1, L2, L3 annotations in Scoris; do not use ticks. Examiner's Comments Most candidates were aware that an equilibrium would be achieved in the flask, and went on to discuss how the forward reaction was favoured in the Haber process. The role of temperature was not quite as well understood, and there were some muddled statements as candidates tried to sort out their ideas.

Question			Answer/Indicative content	Marks	Guidance
					Beside the confusion over the role of temperature, the three most common misunderstandings were: - that pressure is increased in order to speed up the reaction - at equilibrium the *amount* of reactants equals the *amount* of products - that the Haber process uses an enzyme catalyst. This was usually preceded by the use of the term 'optimum conditions', so presumably that term is too strongly linked to enzymes in the minds of some candidates.
	b		**any three from** used [to make] fertiliser; detail – effect on crops / food supply; explosives are used for more than warfare; idea that benefit outweighs the harm;	3	Accept fertilisers make crops grow **Allow** "weapons used for peacekeeping / deterrence / defence" **Examiner's Comments** This question explored candidates' ability to relate concepts of risk and benefit [IaS 6.1] to an actual example. Most candidates realised that the use of ammonia for fertilisers made a justifiable reason for its continued production and some discussed the concept of benefit versus risk. Some candidates found it very difficult to make a considered value judgement, and responses such as "ammonia isn't only used for explosives, it is a valuable resource used to make hair dye" did not gain credit.
			Total	9	

Question			Answer/Indicative content	Marks	Guidance
10		i	15.38 [2] Use 8 [mass of hydrogen] or uses 52 [mass of atoms of all reactants] [1 mark]	2	**accept** correctly rounded answers e.g. 15, 15.4, 15.38, 15.385, 15.3846 …. **Examiner's Comments** The calculation of atom economy was well attempted. A very common mistake was to misread 'the mass of all reactants as the mass of one of each reactant plus each product'. It was very pleasing to see that although a large minority of candidates may have got the wrong answer, they showed enough working to still gain some credit.
		ii	**comments on the size of the atom economy** [it / atom economy] is a small number / is only X ; **explain what it implies** little useful product made / lot of other product [CO_2] / lot of waste / other product harms the environment / waste of raw materials;	2	**Allow** ecf from ai if X is less than 50% only a small number of atoms from reactants become useful products [2] **Assume** "product" is hydrogen unless specified. **ignore** 'sustainability' statements **ignore** hydrogen atoms wasted / not used [incorrect] **Examiner's Comments** Most candidates realised that a low value for atom economy meant a large amount of waste. There was some confusion between atom economy and percentage yield.
			Total	**4**	

Question			Answer/Indicative content	Marks	Guidance
11			FIRST CHECK ANSWER ON ANSWER LINE If answer = 52.2 /52.4 / 52.3 (%) award 4 marks (formula mass of reactants or $MgCO_3$) = 84.3/84 ✓ (formula mass of product or CO_2) = 44 ✓ Correct substitution = 44/84.3 × 100 / 44/84 × 100 ✓ Ans+dec pl= 52.2 / 52.4 / 52.3 (%) (1 decimal place) ✓	4 (AO 2.2 × 3) (AO 1.2)	If no marks awarded for MP3 and MP4 ALLOW correct working towards formula masses for max (2) 24(.3) + 12 + (3×16) / 12 + (2 × 16) ALLOW ecf ALLOW 52.1(%) (Rounding assessed in previous question) <u>Examiner's Comments</u> Most candidates substituted into the formula to give an atom economy. The most common reasons for only scoring partial marks were to think that magnesium oxide was the useful product (rather than carbon dioxide) or to give answers to more than one decimal place.
			Total	4	

Question			Answer/Indicative content	Marks	Guidance
12	a	i	Fertilisers / explosives	1 (AO 1.1)	ALLOW for growth of/nitrates for plants but IGNORE plants alone/ammonia/Haber process
		ii	No change ✓ Equal moles/molecules/particles on each side (of the equation) ✓	2 (AO 2 × 1.1)	Mark separately <u>Examiner's Comments</u> Candidates often expressed some understanding that an increase in pressure favours the side with fewer moles. Application of this principle to this particular equation is very challenging. Only the higher ability candidates recognised that the number of moles of gas on each side were equal so that there is not overall effect. Some candidates introduced the idea of rates into the answer, rather than focussing on equilibria.

<table>
<tr><th colspan="3">Question</th><th>Answer/Indicative content</th><th>Marks</th><th>Guidance</th></tr>
<tr><td></td><td>b</td><td></td><td>Any two FOR:
100% atom economy / all reactants used up idea ✓

No by-products / no waste ✓

raw materials come from the air ✓

sustainable ✓

works at low pressure / AW ✓

Any one AGAINST:
(very) high temperature (needed) / needs a lot of energy/fuel / doesn't give 100% yield / low yield ✓</td><td>3 (AO 3 × 2.1)</td><td>ALLOW 'high atom economy'

IGNORE 'readily available'

IGNORE'renewable'

<u>Examiner's Comments</u>

In order to answer this question, candidates need to refer back to the equation and information in the question. Candidates often made statements which were true, but did not fit closely to the question. For example, some discussed why nitrogen compounds are needed (for fertilisers etc), which is true for all processes. Others made statements which did not quite meet GCSE standard, for example 'nitrogen is free'. Higher scoring answers referred more emphatically to the process described in the stem of the question, stating that the high temperature was a 'reason against' or that the reversible nature of the reaction meant that the yield could not reach 100%. More detailed reasons 'for' included the high atom economy, or the fact that the raw materials are available in the air.</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>6</td><td></td></tr>
<tr><td>13</td><td></td><td></td><td><table><tr><th></th><th>True</th><th>False</th></tr><tr><td>Nitrogen oxides form in an oxidation reaction.</td><td>✓</td><td></td></tr><tr><td>Nitrogen oxides come from impurities in the coal.</td><td></td><td>✓</td></tr><tr><td>Nitrogen oxides are acidic oxides.</td><td>✓</td><td></td></tr><tr><td>Ammonia is an example of a nitrogen oxide.</td><td></td><td>✓</td></tr></table></td><td>2 (AO 2× 1.1)</td><td>All correct = 2
3/2 correct = 1
1 correct = 0</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>2</td><td></td></tr>
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